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APOLLO RCS POSITIVE EXPULSION TANKAGE
PRODUCT IMPROVEMENT PROGRAM
FINAL REPORT - TASK E

SOLUTION OF COMMAND MODULE
AND SERVICE MODULE
BLADDER REPOSITIONING PROBLEMS

Bell Report No. 8514-928006
19 March 1970

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FOREWORD

This report is one of a series of task reports which present the results of a program performed by Bell Aerospace Company during the period July 1967 through September 1969 under Contract NAS9-7182 for the National Aeronautics and Space Administration, Manned Spacecraft Center. Mr. Darrell Kendrick was Technical Monitor of the program for NASA. The Bell Aerospace Program Manager was Mr. R. K. Anderson.

The purpose of the program was to improve and update the Apollo RCS positive expulsion propellant tank assemblies in the areas of performance, reliability, and mission duration. The program effort was divided into the following major tasks, each of which is reported separately.

Task A - Historical Summary Report - A chronological summary of the evolution of the Command, Service, Lunar Module, and other related tankage was prepared. This summary includes data on all configurations considered under the applicable programs and describes related IR&D work at Bell Aerospace Company.

Task B - Long-Term Compatibility Testing - The purpose of this task was to determine the useful operating lifetime of the Apollo configuration RCS tanks as applicable to a mission of extended duration with a specific goal of 12 months. This task consisted of the following sub-tasks:

B-1: Tank Assembly Storage: Three tank assemblies were stored with propellant (N_2O_4, MMH, 50/50 fuel blend) for 12 months at operating pressure. At the end of this time, each tank was subjected to a complete propellant expulsion followed by disassembly and evaluation.

B-2: Bladder Material Compatibility Testing: Teflon bladder material specimens were subjected to rolling of buckled fold tests after 24 hours, 6 months, and 12 months exposure to N_2O_4, MMH, and 50/50 fuel.

B-3: External Flange Seal Evaluation: The effect of initial flange bolt tightening and retightening techniques on the rate of torque decay was evaluated during a 1-year shelf storage period.

Task C - Correlation of Referee Fluid and Propellant in Vibration Testing - The objective of this task was to verify that vibration testing of the Apollo-type bladder with referee fluid is representative of vibration testing with actual propellants. To develop a correlation with sufficient accuracy, the following three areas of testing were pursued:

C-1: Vibration tests were conducted with referee fluid in a plexiglass tank to define the response characteristics of the bladder as affected by ullage level, direction of excitation, and vibration input level.

C-2: Rolling of buckled fold tests were conducted on bladder material specimens to compare endurance in referee fluids with endurance in propellants.

C-3: Full-scale vibration testing was performed on a Lunar Module RCS oxidizer tank with N_2O_4.

Task D - Elimination of Permeation and Bubble Formation - The objective of this task was the elimination, or reduction, of bladder permeation and the associated problem of bubble formation within the bladder. This task included two principal areas of effort:

D-1: Development of Permeation Barrier: This sub-task consisted of design and fabrication of a Teflon bladder with an aluminum foil laminate as a permeation barrier. This bladder, which was of the Service Module oxidizer configuration, was also designed to function in an undersized configuration.

D-2: Elimination of Bubble Formation in Current Apollo Bladder Configuration: Experiments were conducted on both model and full-scale tanks to examine bubble formation phenomena as a function of such variables as temperature, pressure, and ullage level. Data from these tests were used to provide an emperical basis for a better understanding of the mechanisms involved and the effect of each on bubble formation.

Task E - Solution of Command Module and Service Module Bladder Repositioning Problem - The objective of this task was to increase expulsion cycle life of these bladders by eliminating damage due to post-expulsion repositioning.

E-1: Service Module Oxidizer Bladder: The approach used to solve this problem was the use of an undersized configuration similar to that used on the Lunar Module RCS tanks to solve the same problem.

E-2: Command Module Bladder: This problem was associated with the twist mechanism involved in a horizontally mounted tank during the fill cycle. A solution to this problem could not be found within the constraints of the program.

Task F - Integration and Verification of Solutions - The objective of this task was to devise a series of formal tests to demonstrate compliance of design changes from Tasks D-1 and E with the requirements of the applicable Apollo contractor procurement specification.

Service Module oxidizer bladders of the undersized configuration with an aluminum foil laminate were subjected to qualification-level vibration testing and were to be subjected to 20 propellant-expulsion cycles. However, problems occurred during vibration testing which resulted in bladder failure and this task could not be completed within the limits of this program.

Since the Command Module bladder twist problem was not solved (Task E-2), no Command Module tank testing was performed in Task F.

This report covers the effort performed under Task E. The other major tasks are reported individually as follows:

Task	Report Number	Title
A	8514-927002	Historical Summary Report
B	8514-928004	Long-Term Compatibility Testing
C	8514-928005	Correlation of Referee Fluid and Propellant In Vibration Testing
D	8514-928003	Elimination of Permeation and Bubble Formation
F	8514-928007	Integration and Verification of Solutions

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I. INTRODUCTION

The objective of this task was to increase the expulsion cycle life of Service Module Oxidizer and Command Module bladders by overcoming bladder-to-shell friction problems which occur during post-expulsion re-expansion of the bladder.

The Service Module bladder repositioning problem is limited to the oxidizer tank and is caused by a marginal L/D ratio. This problem exists only when repositioning the bladder after a liquid expulsion in the vertical attitude. Since this problem had been solved on the Lunar Module RCS and Saturn IV B APS tanks by incorporation of an undersized bladder design, it was planned to employ the same solution to the Service Module oxidizer tanks. Thus the activity in this phase of this task was limited to adaptation of the undersized design to the SMO bladder to be fabricated containing the aluminum fail permeation barrier developed in Task D of this program.

The twist problem associated with Command Module bladders is limited to cylindrical tanks mounted in a horizontal attitude. The bladder folds tend to twist toward the bottom of the tank when the bladder is collapsed and during subsequent filling operations the weight of the liquid may trap these folds in the bottom of the tank, thus reducing the available bladder volume. If the twist angle is large enough, severe biaxial strains develop in the bladder ends upon complete filling of the tank.

Since bladder folding behavior during an expulsion has a marked influence on the amount of twist experienced during subsequent re-expansion, it was planned to study the effect of each of the following on bladder behavior during expulsion and re-expansion:

1. Elimination of holes in the diffuser tube- flowing through end cones only.
2. Variation of diffuser cone ΔP by changing cone hole patterns.
3. Variation of bladder stiffness particularly in the hemispherical ends.

It was recognized that the above variables, in themselves, may not solve the problem. However, if any should indicate positive beneficial effects on the twist mechanism it was planned to combine them with teflon coating of the shell to determine whether decreasing bladder-to-shell friction would provide sufficient added benefits to solve the problem.

II. SUMMARY

The approach used to solve the Service Module oxidizer bladder repositioning problem was to eliminate bladder-to-shell friction by use of an undersized bladder configuration similar to that used in the Lunar Module RCS tanks. To verify the solution, an undersized bladder of Service Module oxidizer size was subjected to expulsion testing in a plexiglass tank. An aluminum foil laminate was added to this bladder to determine whether such a permeation barrier would perform satisfactorily in an undersized bladder. Eight expulsion tests were performed with the bladder repositioning itself completely in all cases and with no evidence of damage to the aluminum foil laminate.

The problem of bladder twist in the horizontally mounted Command Module tanks was investigated from two standpoints: decreasing bladder-to-shell friction to a beneficial degree by teflon coating the shell and minimizing bladder twist by diffuser redesign. Neither of these approaches was effective and the twist problem associated with horizontal tanks was not solved.

III. DISCUSSION

A. Task E-1: Service Module Oxidizer Bladder Repositioning Problem

1. Design and Analysis

a. Description of Problem

The Service Module repositioning problem is confined to the oxidizer tank and is caused by a marginal L/D ratio which results in high bladder-to-shell friction forces. The problem exists only when re-expanding the bladder after a liquid expulsion in the vertical attitude. During a liquid expulsion, the bladder is displaced downward in the tank due to gravity. At the end of the expulsion, the excess bladder material is collected at the bottom of the tank in the form of numerous tight folds and creases as shown in Figure 1. During subsequent re-expansion of the bladder, the cylindrical portion expands radially and contacts the tank shell before either of the hemispherical ends expands to any appreciable degree. Thus, due to the marginal L/D ratio, friction forces between the bladder and shell may exceed the available lifting force supplied by the pressure within the bladder and the bladder cannot reposition itself fully. As a result, the top hemisphere of the bladder is not supported by the shell and yields due to biaxial stress during subsequent servicing and loading operations.

b. Solution of Problem

The repositioning problem was solved on the Lunar Module RCS and Saturn IV B APS tanks by incorporation of an undersized bladder which prevents bladder-to-shell contact in the cylindrical section until after full re-expansion of the bladder. Another possible solution to the Service Module repositioning problem would be to coat the shell internally with

Teflon to reduce friction. Since the undersized bladder concept is simpler, more economical, and has been successfully qualified on both the Lunar Module and Saturn IV B tank programs, the Teflon coating concept was not pursued.

Accordingly, a bladder of the Service Module oxidizer (SMO) size was designed with the cylindrical section undersized 2% diametrically, similar to the Lunar Module and Saturn IV B bladder design. In addition, an aluminum foil laminate was added as a permeation barrier, based on the results of Task D of this program during which it was demonstrated that a film construction of this kind could be used in an undersized bladder. The results of Task D are reported in Bell Report 8514-928003. The bladder design is shown in Figure 2; the nominal design film thickness was 12.5 mil, consisting of 8 mil 20% TFE/FE codispersion, 1/2 mil aluminum foil, 4 mil FEP. The combining of these two innovations allowed a study to be made of the effectiveness of the foil permeation barrier as well as a demonstration of the effectiveness of the undersized bladder as a solution to the repositioning problem on the SMO tank.

2. Test Program

a. Test Procedure

One undersized SMO bladder containing an aluminum foil laminate was installed into a plexiglass tank and eight expulsions were performed in accordance with the expulsion test portion of Bell Procedure 8514-928002. Slight modifications in the procedure were required to adapt to the pressure and fluid limitations of the plexiglass tank. These modifications were principally as follows:

1. Freon TF was used in lieu of propellant.
2. Tank operating pressure was 20 psig during expulsions.

b. Test Apparatus

The test installation for expulsion testing is shown schematically in Figure 3.

c. Test Hardware

The test hardware consisted of one (1) 8514-471008-1 bladder S/N 70-1, one (1) 8271-471233 diffuser assembly S/N 29, and associated hardware to make a plexiglass tank assembly as shown in Figure 4.

d. Assembly

The bladder was assembled on the diffuser tube as shown in Figure 5. Eight longitudinal orientation lines were made on the bladder to facilitate evaluation of bladder repositioning characteristics. The bladder assembly was then evacuated and folded as shown in Figures 6 and 7 and installed into the plexiglass shell. Following the assembly into the plexiglass shell a 10 psi helium leakage test was performed on the bladder. After 1 hour, zero leakage was noted.

e. Test Description

Eight expulsions were performed using Freon TF as the expulsion medium. The first four expulsions were made with the tank in the vertical, flange-down position and the last four in the horizontal position. Volumetric flow rate was approximately equivalent to the specification requirement and all expulsions were terminated by command shutdown at an indicated tank assembly ΔP of 3 to 7 psi. The tank was loaded and 5% ullage was drained in the vertical flange-down position for all tests. Post-expulsion bladder re-expansion was performed in the position of expulsion. A 10-psi helium leakage test was performed on the bladder prior to the first and fifth and after the eighth expulsions.

f. Test Results

1. Vertical Expulsions

As expected, the bladder repositioned itself completely within the tank when re-expanded after each vertical expulsion with no visible evidence of strain. The cylindrical section of the bladder did not touch the tank wall until complete vertical positioning had occurred. Figure 8 shows the bladder half-way through the first expulsion and Figures 9 and 10 show the bladder appearance after completion of expulsion. As shown in Table 1 and Figure 11, expulsion efficiencies exceeded 99% at a tank assebmly Δ P of 6 psi.

2. Horizontal Expulsions

As in the case of the vertical tests, expulsion efficiencies in the horizontal attitude exceeded 99% at a tank assembly ΔP of 6 psi as shown in Table 1 and Figure 12. The first horizontal expulsion (No. 5) was not instrumented sufficiently to obtain an efficiency curve. Figures 13 and 14 are top and end views of the plexiglass tank after completion of the first horizontal expulsion.

Re-expansion of the bladder in the horizontal position after the first expulsion resulted in a 15° twist of the bladder. The same twist was experienced after each of the remaining three horizontal expulsions. In each case, the twist was removed by turning the tank to the vertical position, partially collapsing the bladder and re-expanding in the vertical position.

3. Bladder Condition

After each re-expansion, the bladder was visually checked through the plexiglass shell and no visible damage or residual hard creases were noted. Helium leakage tests of the bladder were performed prior to the first and fifth expulsion and following the eighth expulsion. With a Δ P of 10 psi across the bladder for a period of 1 hour, zero leakage was recorded in each case.

B. Task E-2: Command Module Bladder Repositioning Problem

1. Design and Analysis

Since the Command Module RCS tanks are mounted horizontally, the bladders are susceptible to twisting during fill operations. Bladder twist is a random occurrence which depends upon folding patterns developed in the bladder during expulsion and/or subsequent evacuations as shown in Figure 15. Figure 16 is a sketch showing bladder folding patterns after expulsion and evacuation and indicates the downward rotation of a point on a fold due to propellant weight during filling. As fold A rotates and expands, it reaches the tank wall and a twist angle θ is established. At complete fill pressurization, the bladder membrane develops torsional restoring moments which are opposed by the friction between the bladder and the tank wall. In Apollo-type tanks, the friction forces are generally large enough to prevent reduction of the angle of rotation by bladder slippage and the result is incomplete repositioning of the bladder within the shell. The Apollo Command Module shell and bladder geometries are such that a bladder twist angle of 20° can be experienced without bladder damage; however in some cases bladder twist angles as great as 80° have been observed after a few expulsion cycles in Command Module oxidizer tanks. Figure 17 shows examples of twist damage on a Command Module oxidizer tank after repetitive expulsion cycle testing with propellant.

It has been determined by observation of previous twist tests in plexiglass tanks that twist forces buckle the hemispheres of the bladder and produce a pattern of folds which become tighter as the bladder is pressurized. Since the folds take up bladder material, the hemispherical bladder sections are initially reduced in volume. This creates a gap between the bladder and tank wall which is bridged by deformation of the bladder material when internal pressure is applied. The folds are in diagonal tension and the bladder material between the folds is subjected to biaxial tension stresses and is thereby strained to increase the bladder volume to comply with the internal volume of the shell. After subsequent expulsion and fill operations, new folds develop, depending upon twist angle, and sequences of tight creasing and biaxial tension tend to occur in many parts of the bladder hemispherical surfaces. This sequence of loads is damaging.

Two approaches to the solution of the twist problem were considered as part of this task: reduction of bladder-to-shell friction and reduction or elimination of bladder twist during expulsion and evacuation.

Reduction of Friction: The problem of bladder-to-shell friction was eliminated in vertically mounted tanks by use of an undersized bladder. This bladder design, however, does not solve the friction problem in horizontal tanks. Reduction of friction without possible contamination of the pressurization system would involve coating of the internal surface of the tank shell with Teflon. Previous analyses conducted during the performance of Contract NASw-1317 by Bell Aerospace for the George C. Marshall Space Flight Center showed that the maximum coefficient of friction in a Command Module oxidizer tank which would limit bladder twist to 20° is 0.045. Results of laboratory tests at Bell have shown that the coefficient of friction between Teflon FEP (the outer laminate of the Apollo bladder) and Teflon TFE is 0.15 and between FEP and FEP the coefficient is 0.21. For this reason, coating of the shell was not considered to be a satisfactory solution to the twist problem.

Reduction of Twist: During the latter portion of propellant expulsion in a horizontally mounted tank, the bladder is compressed tightly around and below the diffuser tube, sealing off the holes in the tube and limiting propellant flow to the cones at each end of the bladder. Thus, the final folding pattern of the bladder at the end of an expulsion is dependent upon the flow path of the propellant. For this reason, it was felt that modifications in the number and pattern of the diffuser holes might result in a beneficial decrease in bladder twist angle.

Several design approaches were studied and evaluated. These included variation of the diffuser cone flow pattern and ΔP by varying the number, size, and pattern of the holes in order to control the orientation of the bladder extremities. The objective of these modifications (as listed in Table 2) was to minimize bladder twist at the end of an expulsion and, if possible, prevent the bottom of the bladder from lifting at the end of an expulsion. If this could be accomplished, position A on the bladder as shown in Figure 16 would not change and the twist angle would remain zero.

2. Test Program

a. Test Procedure

The bladders and diffuser were assembled, installed into the Command Module oxidizer size plexiglass tank, and tested in accordance with the procedure contained in Appendix A.

b. Test Apparatus

The test installation for expulsion testing is shown schematically in Figure 3.

c. Test Hardware

The test hardware consisted of one CMO diffuser, P/N 8271-471200-7; two CMO SIZE BLADDERS P/N 8271-

471160-1 and 8271-471148-3; and associated hardware to make a plexiglass tank assembly of CMO size as shown in Figure 15.

d. Test Description

A series of 10 tests was conducted consisting of a total of 90 liquid expulsions. The first six tests were conducted with a 8271-471160-1 CMO bladder of qualified flight configuration and using water as the expulsion medium. This bladder has a nominal 0.006 inch film thickness in the cylindrical portion, tapering gradually to a film thickness of 0.009 inch in the hemispherical ends. The last four tests were conducted with a 8271-471148-3 CMO bladder which has a nominal film thickness of 0.006 inch throughout. Freon TF was used as the expulsion medium for the last four tests.

All loading, expelling, and servicing were performed with the tank mounted in the horizontal attitude. Volumetric flow rates during all expulsions were approximately equivalent to the specification requirement for CMO tanks.

The bladder and plexiglass shell were marked with longitudinal orientation lines for use in measuring bladder twist. Bladder leakage tests were performed periodically during the test program to verify bladder integrity.

Since bladder twist is normally a random occurrence, it was felt desirable to establish a twist pattern in the bladder prior to testing. Thus, after assembly into the plexiglass tank, the bladder was expanded to the shell wall with 2 psig nitrogen pressure and the diffuser flange was then rotated one bolt hole counter-clockwise. This resulted in the bladder being twisted clockwise 4.5 inches or 36° on its cylindrical section. The assembly was held in this fashion for 2 hours to allow a permanent set. The bladder internal pressure was then vented and the bladder rotated 1.5 inches counter-clockwise, resulting in a residual twist of 3 inches clockwise (24°) from the new reference zero of the flange. This was used as the residual (pre-test) twist for the first series of tests.

Prior to each series of tests, the bladder was expanded to the wall of the tank and residual twist was recorded. Twist measurements for each expulsion test were made after bladder evacuation and liquid loading. Since twist measurements are stated herein in inches, it should be noted that 1 inch of twist is equivalent to 8 degrees of rotation.

e. Test Results

Test Series No. 1 through 3

These tests were performed to determine whether deletion of the holes in the tubular portion of the diffuser assembly would affect bladder twist.

Test Series No. 1 consisted of 10 expulsions with the normal diffuser configuration to establish a baseline of bladder twist behavior. Bladder twist after liquid loading varied from 3.0 to 6.0 inches clockwise, with individual measurements of 4.0, 5.2, 6.0, 4.5, 3.0, 5.5, 4.2, 5.0, 4.6, 5.0.

Test Series No. 2 consisted of 10 expulsions with the holes in the tubular portion of the diffuser taped shut and flowing through the end cones only. Bladder twist after liquid loading varied from 0.5 inch counter-clockwise to 1.5 inches clockwise, with individual measurements of 1.5 cw, 0.7 cw, 0.5ccw, 0.5ccw, 0.7 cw, 0.9 cw, 0.8 cw, 0.7 cw, 0.5 cw, 0.4 cw.

This test series indicated a distinct improvement in bladder twist over Test Series No. 1, with the degree and range of twist approximately half the values in Series No. 1.

Test Series No. 3, consisting of 8 expulsions, was conducted in same manner as Test Series No. 1 to re-affirm the baseline data and determine the validity of the improvement shown in Test Series No. 2. A residual (pre-test) twist of 1.0 inch cw was established, with bladder twist after liquid loading varying from 0.6 inch clockwise to 0.8 inch counter-clockwise. Individual measurements were 0.6 cw, 0.5 cw, 0.4ccw, 0.8ccw, 0.7ccw, 0.6ccw, 0.7ccw, 0.7ccw.

Obviously, Test Series No. 3 not only did not verify the baseline data of Test Series No. 1, but also showed less bladder twist than Series No. 2. Since the only difference between tests was the pre-programmed twist prior to Test Series No.1, it was felt that these tests should be repeated with the same pre-test twist imposed on all three tests.

Test Series No. 4 through 6

These tests were a repetition of test series No. 1 through 3, except that the pre-programmed bladder twist of 4.5 inches (36°) clockwise was used on each series.

Test Series No. 4, consisting of 8 expulsions, was a repeat of Test Series No. 1, with the normal diffuser configuration. A pre-test residual twist of 4 inches clockwise was experienced on this series, compared to a residual twist of 3 inches clockwise on Series No. 1. The bladder twist after liquid loading varied from 1.5 inches to 3.5 inches counter-clockwise, compared to 3.0 to 6.0 inches clockwise for Test Series No. 1. Individual twist measurements for this series were 1.5 , 2.5, 3.1, 2.9, 3.0, 3.5, 3.2, 3.2.

Test Series No. 5, consisting of 7 expulsions, was made with the holes in the tubular portion of the diffuser taped shut and flowing through the end cones only. Residual pre-test twist for this series was 3.8 inches clockwise, compared with 1.4 inches clockwise for Series No. 2. The bladder twist after liquid loading varied from 4.0 to 5.5 inches clockwise, compared to 0.5 to 1.5 inches clockwise for Series No. 2. Individual twist measurements for this series were 4.5, 5.3, 5.5, 4.1, 4.0, 4.1, 4.8.

Test Series No. 6, consisting of 7 expulsions, was made, as was Series No. 4, with the normal diffuser configuration with all holes flowing. The residual (pre-test) twist was 3.7 inches compared with 4.0 inches for Series No. 4. The bladder twist after liquid loading varied from 3.8 to 5.4 inches clockwise, with individual twist measurements of 3.8, 3.9, 4.5, 5.3, 5.3, 5.4, 5.4.

The results of Test Series 4 through 6 were much the same as Series 1 through 3, in that the absence of holes in the tubular portion of the diffuser showed no definable effect on bladder twist.

Summation of Test Series No. 1 through 6

A study of the test data, as shown in Table 2 , indicates that elimination of the diffuser tube holes has no distinct advantage over the current configuration. However, observation of bladder behavior during the tests did indicate a more favorable folding pattern during the tests with the diffuser tube holes eliminated in that during these tests the bladder exhibited less of a tendency to lift from the bottom of the tank. Thus, since the lifting of the bladder should allow more rotation in the cylindrical section of the tank, it would appear that the elimination of diffuser tube holes may contribute to decreasing the angle of twist.

Test Series No. 7 through 10

These tests were performed to determine whether changing the hole pattern in the diffuser end cones would affect the orientation of the bladder extremities during the final phase of an expulsion and thereby have a beneficial effect on bladder twist. Although the size and number of holes were varied (as shown in Table 2) during these tests, the holes were sized so that the pressure drop through the cones would be consistent with the original design.

After experience gained during the previous six test series, it was felt that if test conditions could be chosen which would increase the tendency of the bladder to twist, then any solution or improvement would be much easier to note. Therefore, for this test series, it was decided that a less-stiff bladder should be used, as the 8271-471148-3 (0.006 inch thick throughout) instead of the current 8271-471160-1 (0.006 inch thick with 0.009 inch hemispherical ends). In addition, Freon TF was substituted for water because of its greater density and its softening effect on teflon.

Since the pre-programmed twist did not appear to be helpful in the previous series of tests, it was not used for this series. Therefore, since the tank was disassembled prior to each test series, the residual (pre-test) twist was zero for each series.

<u>Test Series No. 7</u>: These tests, consisting of 9 expulsions, were performed to determine the effect, if any, of lowering the centerline of the liquid flow path at the cones, thus decreasing the distance the bladder would have to lift the liquid. This was accomplished by modifying the diffuser cones so that the holes were in the bottom 90° quadrant of each cone as shown in Figures 18 and 19.

Bladder twist after liquid loading varied from 1.7 to 3.0 inches counter-clockwise, with individual measurements of 3.0, 2.8, 2.1, 1.7, 2.0, 2.1, 2.2, 1.8, 1.8.

<u>Test Series No. 8</u>: These tests, consisting of 8 expulsions, were performed to determine the effect of lowering the centerline of the liquid flow path, as defined in Test Series No. 7, plus elimination of flow through the tubular portion of the diffuser.

Bladder twist after liquid loading varied from 1.0 to 3.0 inches counter-clockwise, with individual measurements of 3.0, 1.7, 1.2, 1.0, 1.7, 1.4, 1.2, 1.7.

Comparison of data from Test Series No. 7 and 8 again indicates that the presence or absence of holes in the tubular portion of the diffuser has no measureable effect on the twist mechanism of the bladder.

Test Series No. 9: These tests, consisting of 15 expulsions, were performed to further establish whether lowering the centerline of the flow path was advantageous by adding holes to the top 90° quadrant in addition to the bottom quadrant of the cones. It was felt that addition of the holes on top would help to prevent the bladder from twisting because of the positive gas-to-liquid ΔP across the bladder during the latter stages of the expulsion. For this series, the diffuser tube holes remained taped, allowing flow only through the upper and lower quadrants of the cones.

Bladder twist after liquid loading varied from 1.9 inches clockwise to 2.8 inches counter-clockwise, with measured values of 1.3 cw, 1.9 cw, 0.4 cw, 0.5ccw, 1.5ccw, 1.5ccw, 2.8ccw, 2.2ccw, 1.5ccw, 0.9ccw, 0.6ccw, 1.7ccw, 0.9ccw, 0.7ccw.

Although the range of twist during Test Series No. 9 is greater than that of 7 or 8, it progresses from clockwise to counter-clockwise, thus imposing no greater strain on the bladder. However, the maximum variation of 2.8 inches shows no improvement over either No. 7 or No. 8, each of which had a maximum variation of 3.0 inches.

Test Series No. 10: This series, consisting of 8 expulsions, was performed using a standard configuration diffuser to establish a base line for evaluating Test Series 7, 8, and 9.

. Bladder twist after liquid loading varied from 0.5 to 1.5 inches counter-clockwise, with individual measurements of 1.5, 0.8, 0.7, 0.5, 0.9, 0 9, 0.8, 0.8.

Summation of Test Series No. 7 through 10

As shown in Table 2, Test Series No. 7 and 8 were similar in both degree and direction of twist. Although Test Series No. 9 had a greater range of twist, the degree of twist from the pre-test reference point was no greater than that of No. 7 and 8. The final baseline test (Series No. 10) showed a much smaller range and degree of twist with the current configuration diffuser tube. The fact that Test Series No. 10, using a thin bladder with Freon TF, also showed less twist than similar baseline tests No. 1, 3, 4, and 6 using a stiffer bladder with water indicates that the random twist pattern from one bladder to another is too great to establish a valid comparison within the defined limits of this program.

IV. CONCLUSIONS

SMO Repositioning Problem

The repositioning problem associated with Service Module oxidizer tanks can be eliminated by use of an undersized bladder configuration similar to that used in the LM RCS and SIVB APS positive expulsion propellant tanks.

An expulsion cycle capability exceeding 20 expulsions was demonstrated on the undersized bladder design during the LM and SIVB tank programs. Additional confidence in this configuration was gained during the performance of the work described herein, in which an undersized bladder of SMO size, containing an aluminum foil laminate was installed into a tank and subjected to eight expulsions and re-expansions with no discernible damage, even to the foil laminate.

CM Repositioning Problem

Elimination of the bladder repositioning problem in the Command Module tanks due to twist cannot be accomplished by Teflon coating the shell to reduce friction or by altering the flow configuration through the diffuser assembly. It is also apparent that combining the coating with diffuser redesign would not eliminate the bladder twist problem.

Study of the mechanisms involved in bladder twist has led to the conclusion that any tank of similar design, when mounted in the horizontal attitude, will not be statistically capable of the number of expulsion cycles normally desired for a high confidence level in reliability assessment due to possible twist damage incurred during servicing and loading.

It should be noted that testing experience on Command Module tanks has shown that twist severity is progressive and subsequent bladder damage is cumulative with successive expulsion cycles. Thus, while twist can be severe enough to result in bladder failure during repetitive cycling, reliability assessment of actual test results has resulted in a mission reliability of 0.9841 for the CMF tank and 0.9890 for the CMO tank at a 90% LCL.

V. RECOMMENDATIONS

SMO Repositioning Problem

If it should be desirable to increase the present specification requirement of six expulsion cycles to 20 expulsion cycles for the Service Module oxidizer tank, it is recommended that the undersized bladder design be incorporated.

It is also recommended that future tank designs consisting of similar materials and similar or greater length/diameter ratios should also utilize an undersized bladder.

CMO Repositioning Problem

It is recommended that, in designing vehicular or system installations, provision should be made for mounting tanks so that loading and servicing may be accomplished with the tank assembly in the vertical attitude. Tank assemblies, such as the Command Module tanks, once loaded, will perform satisfactorily in the presence of radial acceleration forces; however repetitive expulsion and evacuation for loading under these conditions can result in bladder damage and potential failure.

Dimensional analysis has shown that the current Command Module tanks would not experience bladder damage due to twist if the tanks were loaded to not more than 90% of total volume. Since these tanks are vacuum-loaded, it should be feasible to replace the existing practice of loading full and then draining ullage with a practice of loading to ullage level only. If present Apollo experience should indicate that 10% ullage is acceptable in these tanks, then an expulsion capability of 20 cycles could be reliably demonstrated.

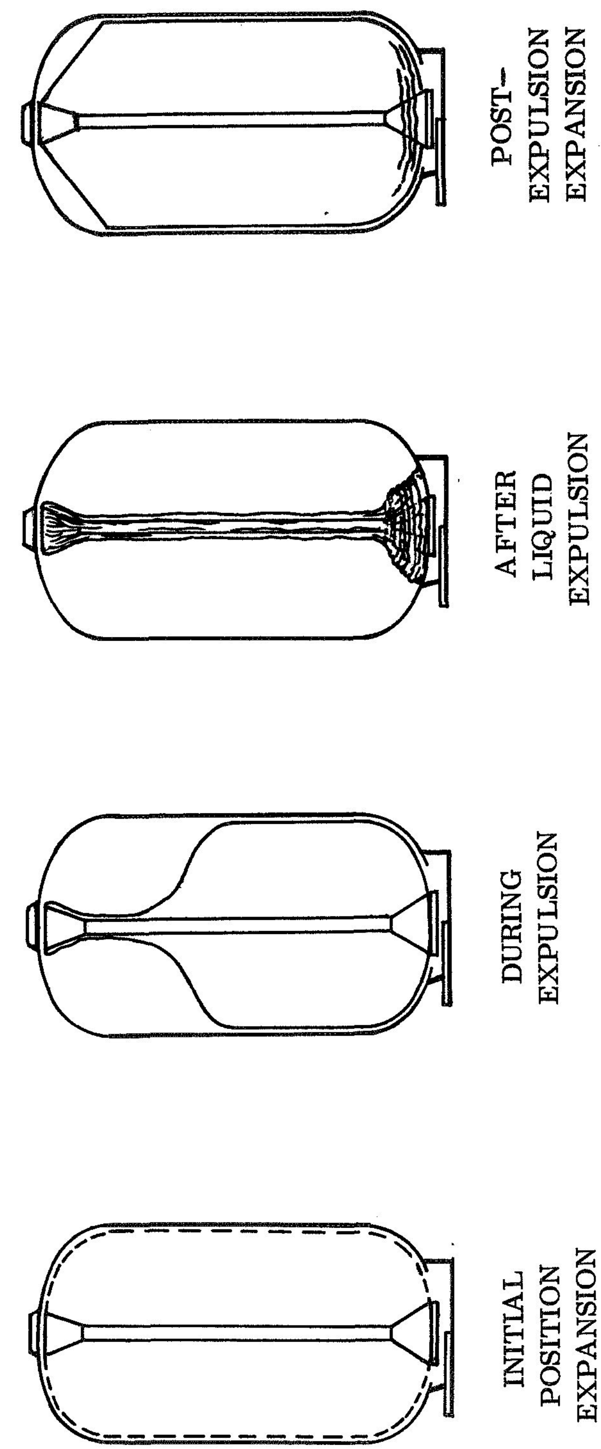

FIGURE 1. SEQUENCE OF TENSION DEVELOPMENT IN BLADDER

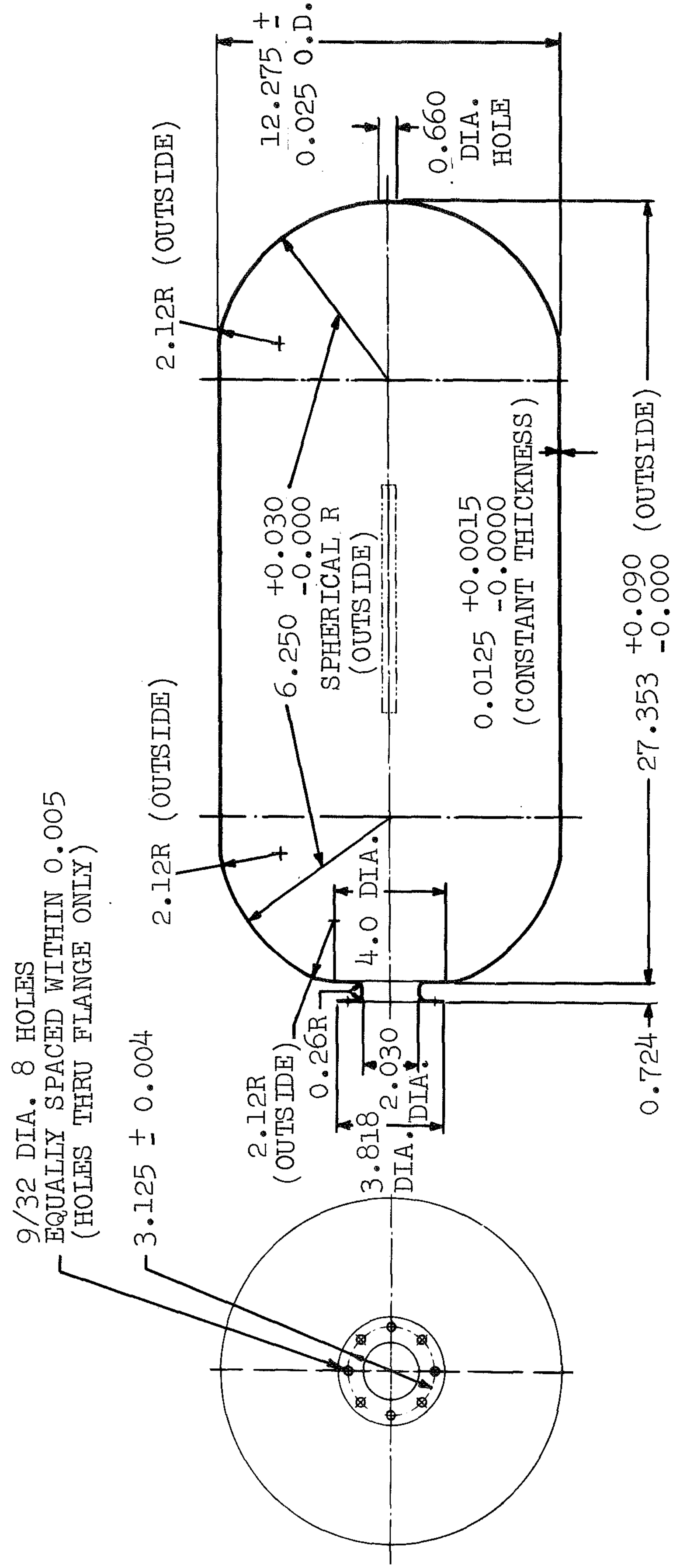

FIGURE 2. EXPULSION BLADDER

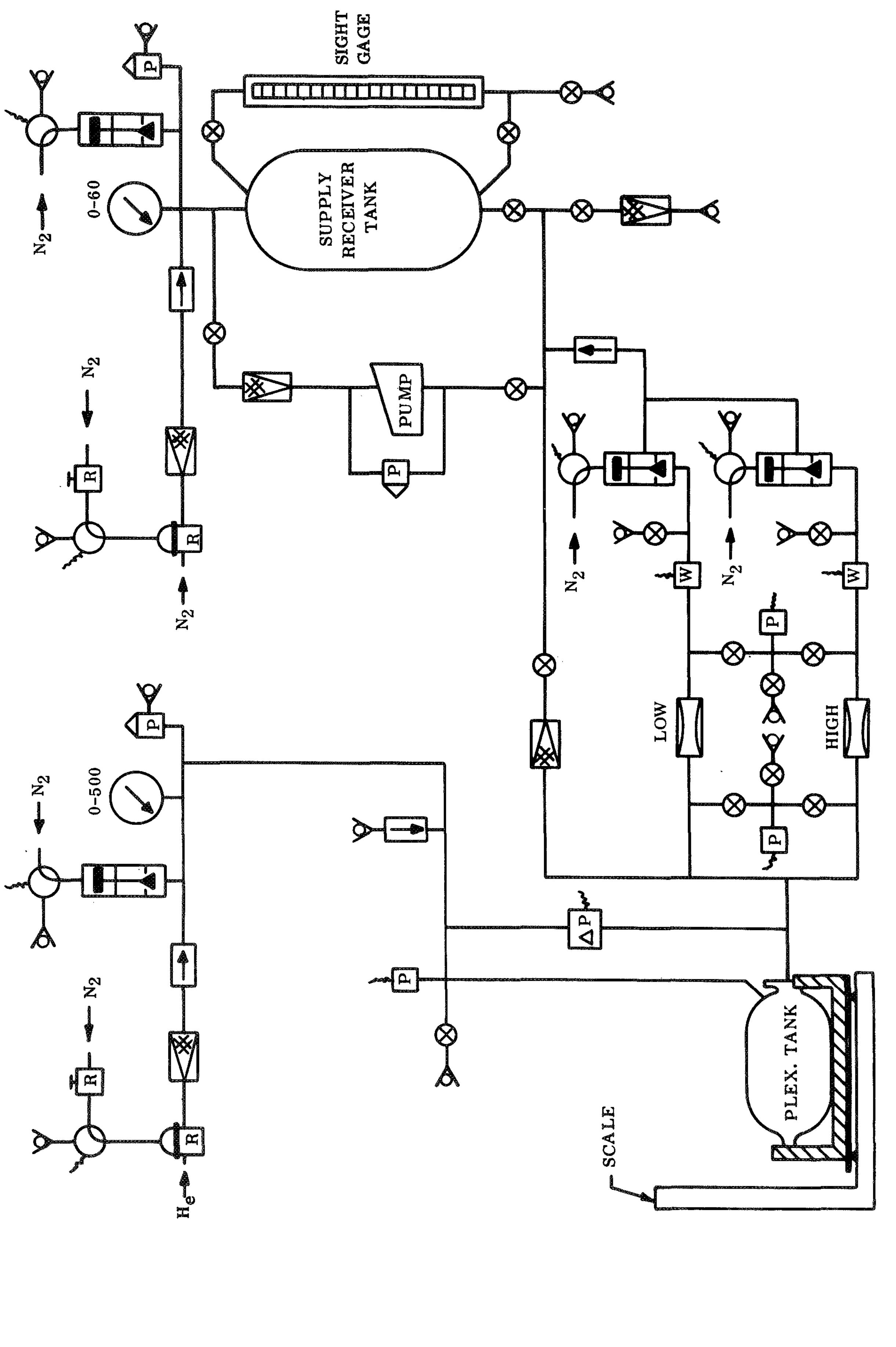

FIGURE 3. EXPULSION TEST CELL SCHEMATIC

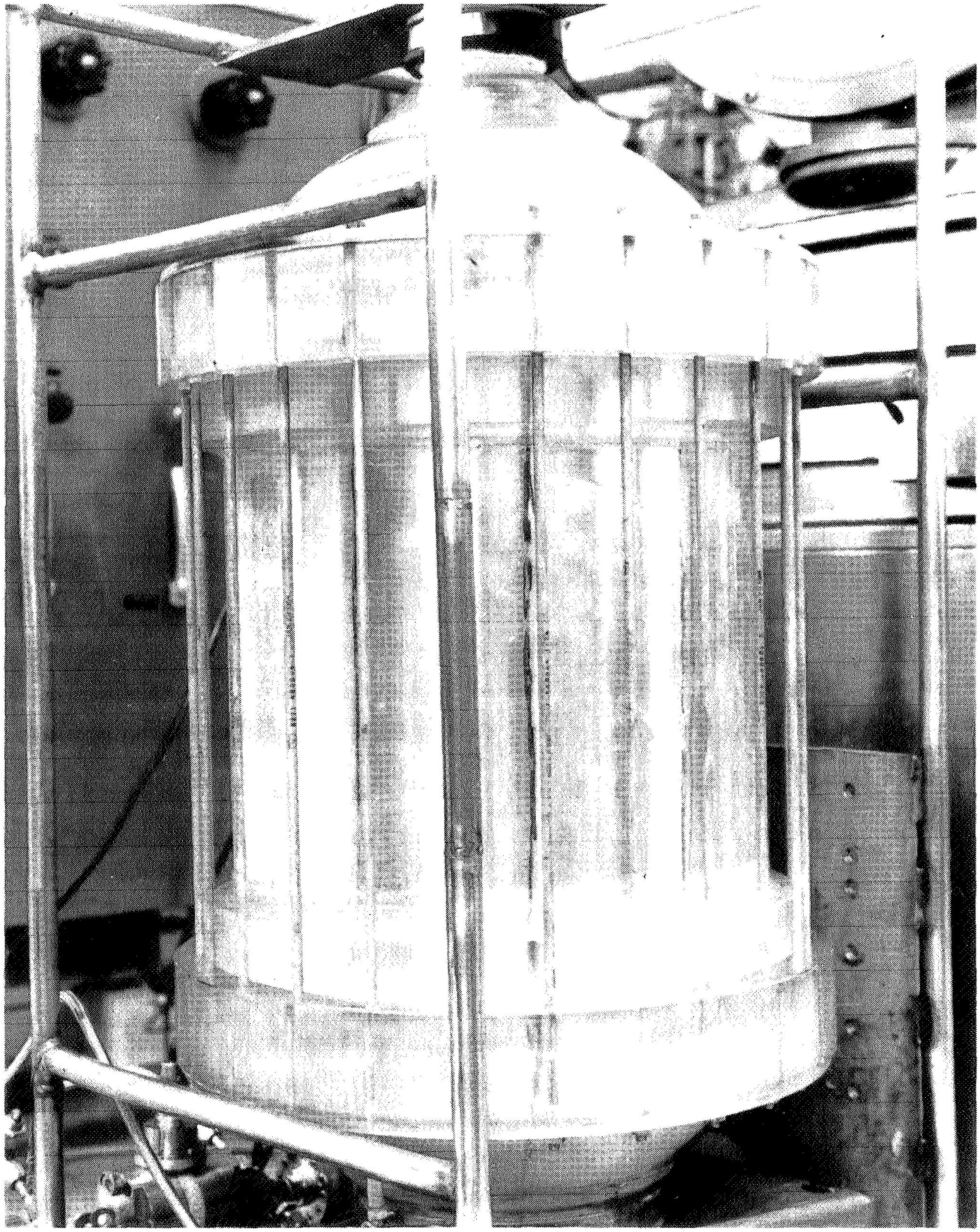

FIGURE 4. PLEXIGLASS TANK ASSEMBLY (SMO)

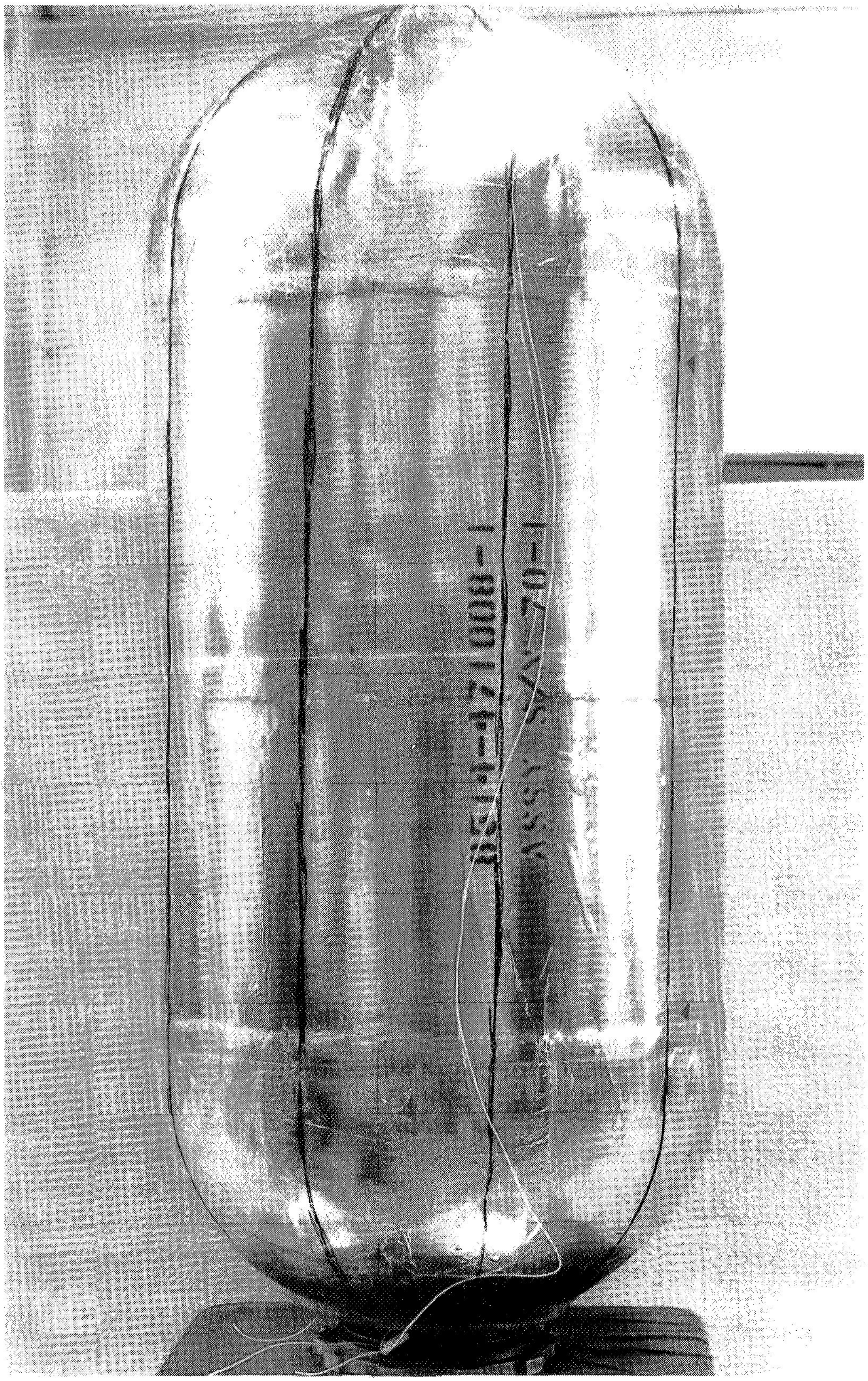

FIGURE 5. BLADDER ASSEMBLY, UNDERSIZED WITH FOIL LAMINATE (SMO)

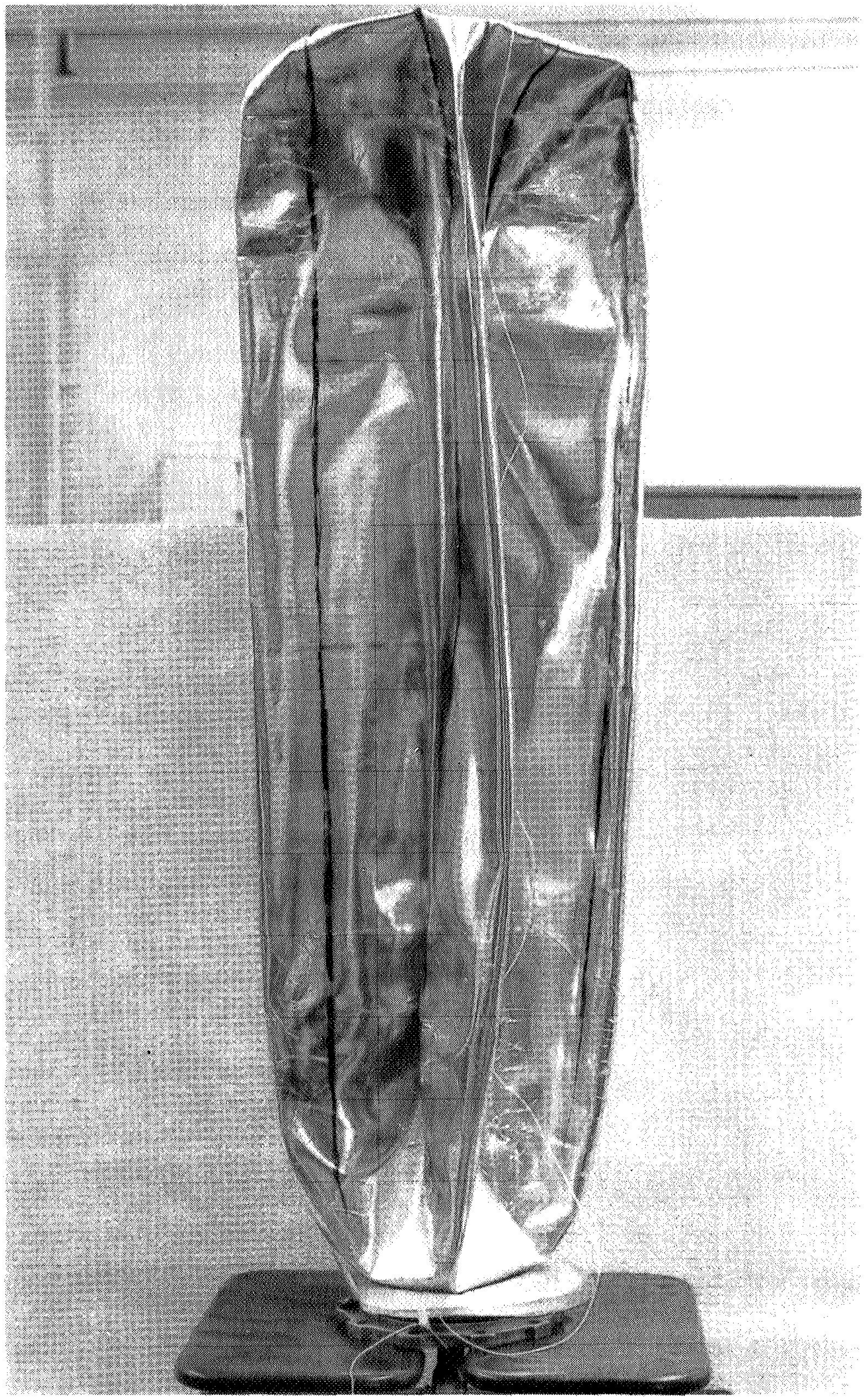

FIGURE 6. BLADDER FOLDING SEQUENCE FOR INSTALLATION (SMO)

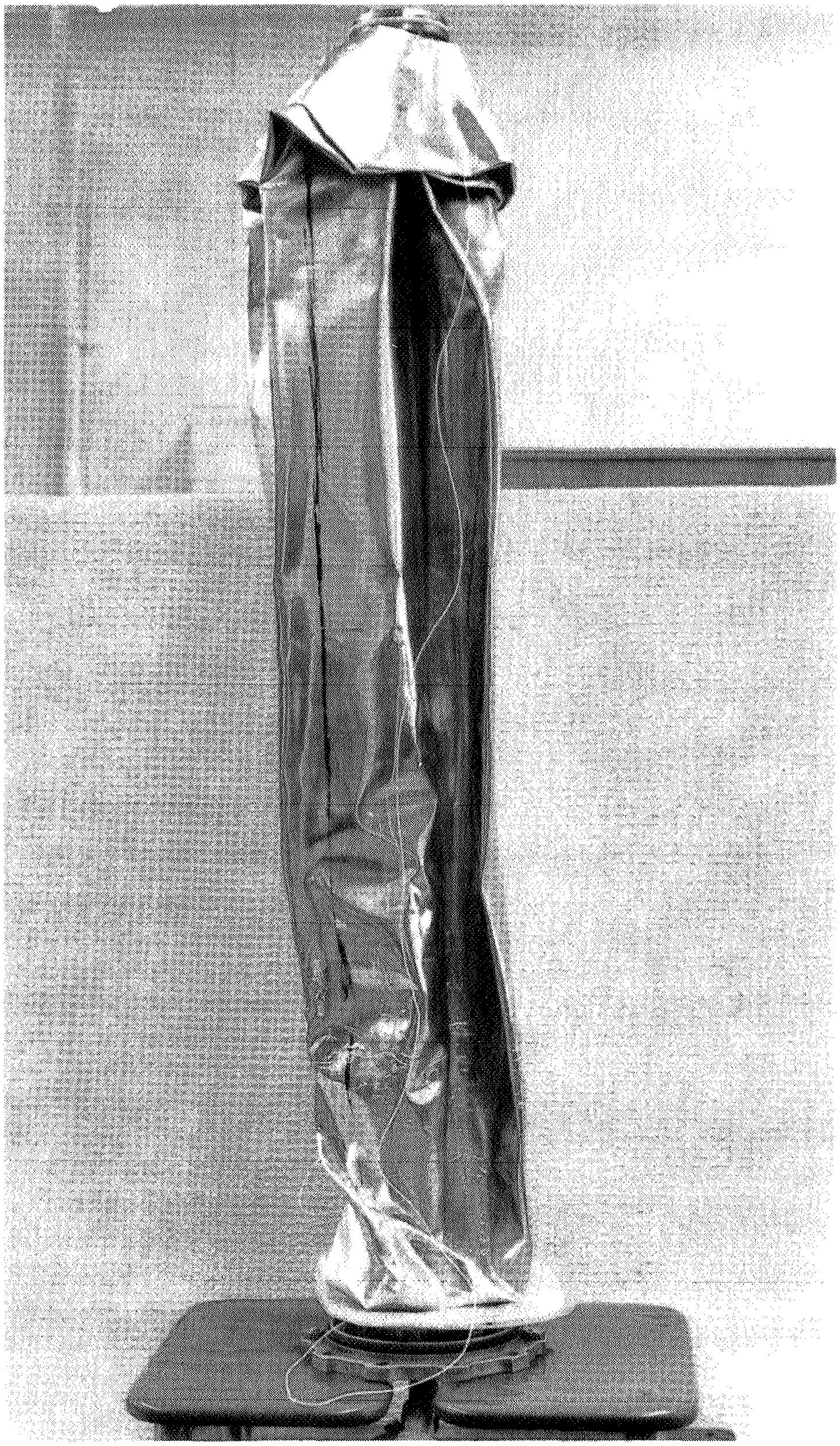

FIGURE 7. BLADDER FOLDING SEQUENCE FOR INSTALLATION (SMO)

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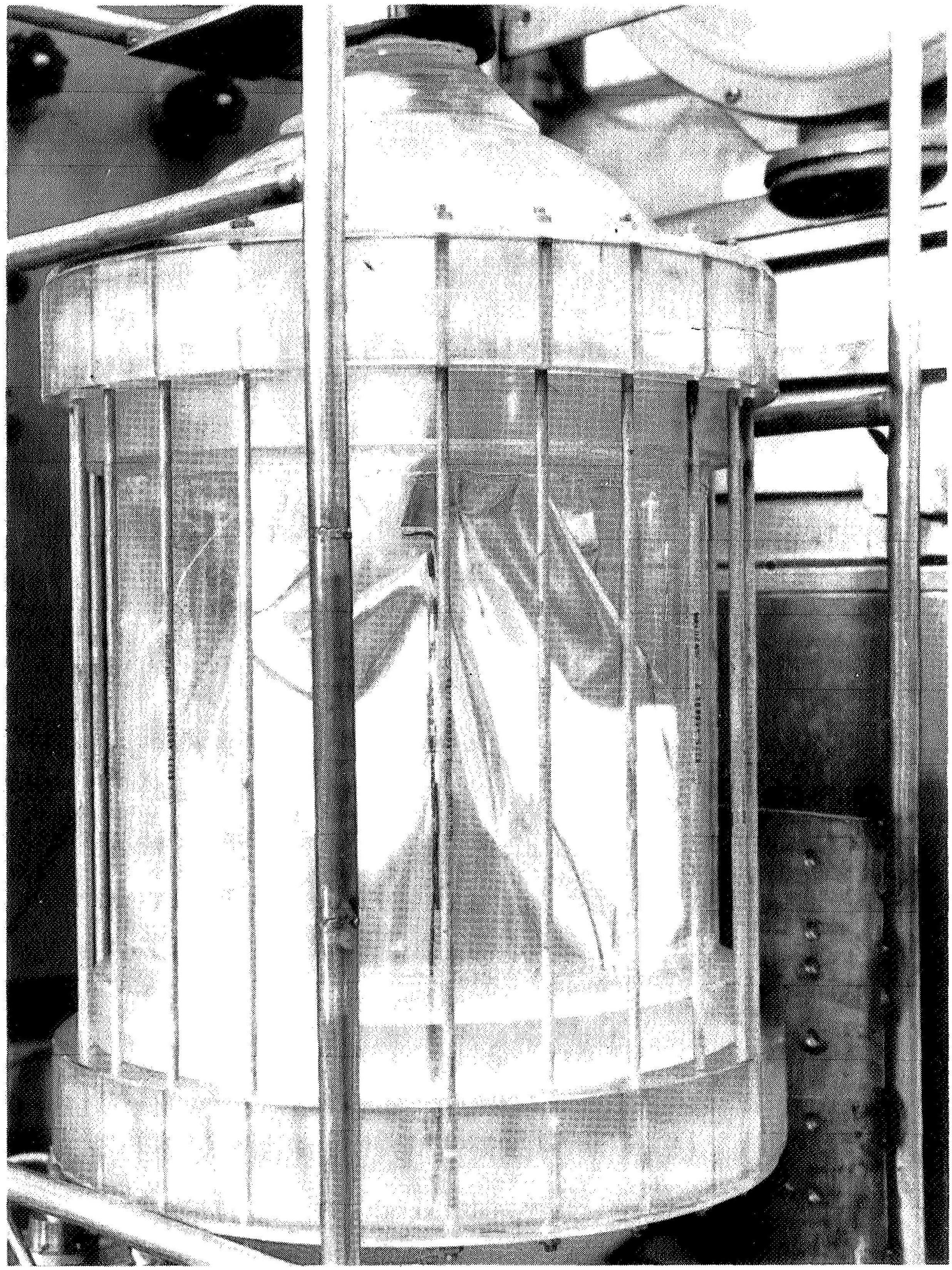

FIGURE 8. TEFLON/FOIL LAMINATE BLADDER - VERTICAL EXPULSION - 50% EXPELLED

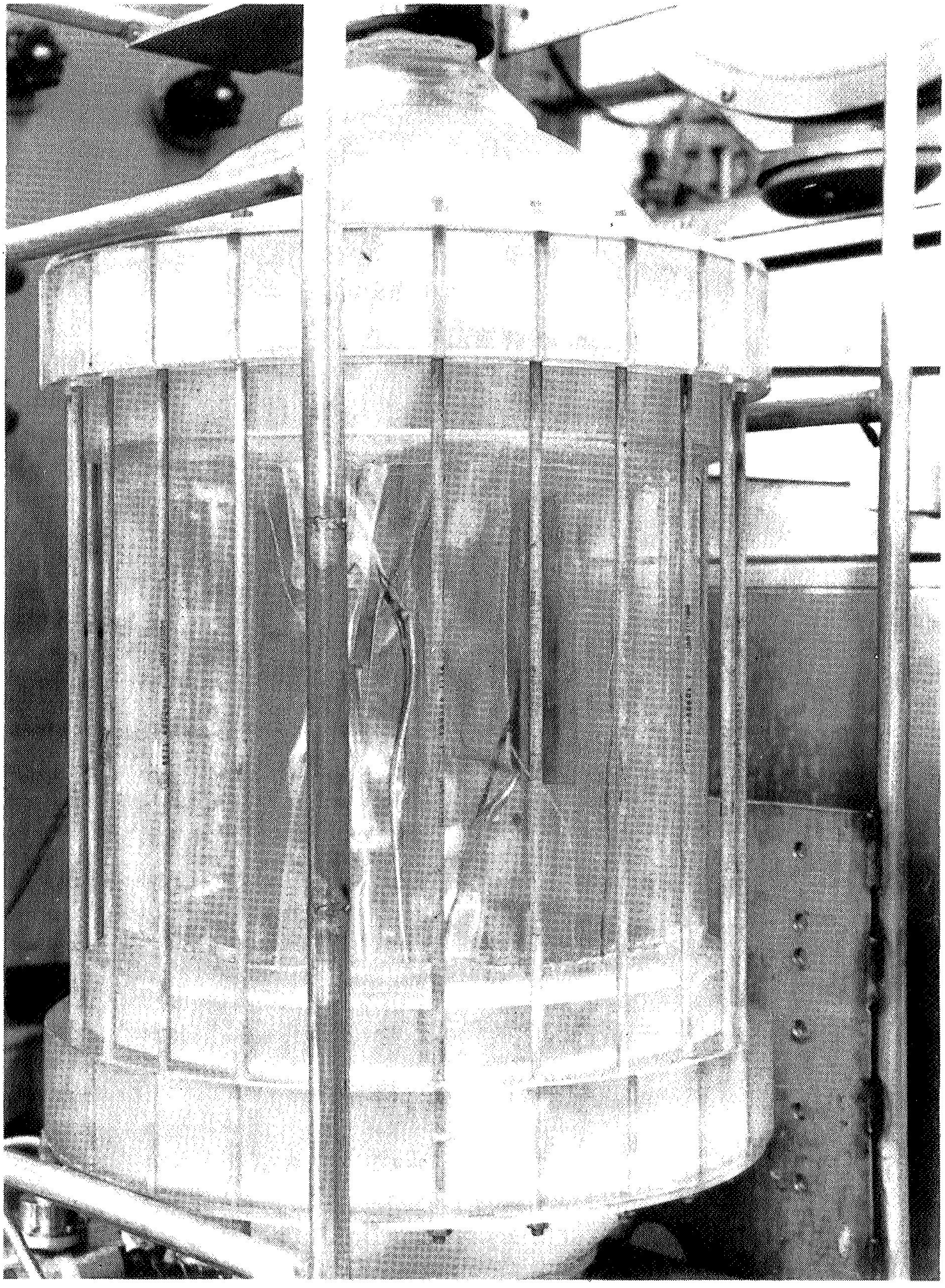

FIGURE 9. TEFLON/FOIL LAMINATE BLADDER - VERTICAL EXPULSION - 100% EXPELLED - SIDE VIEW

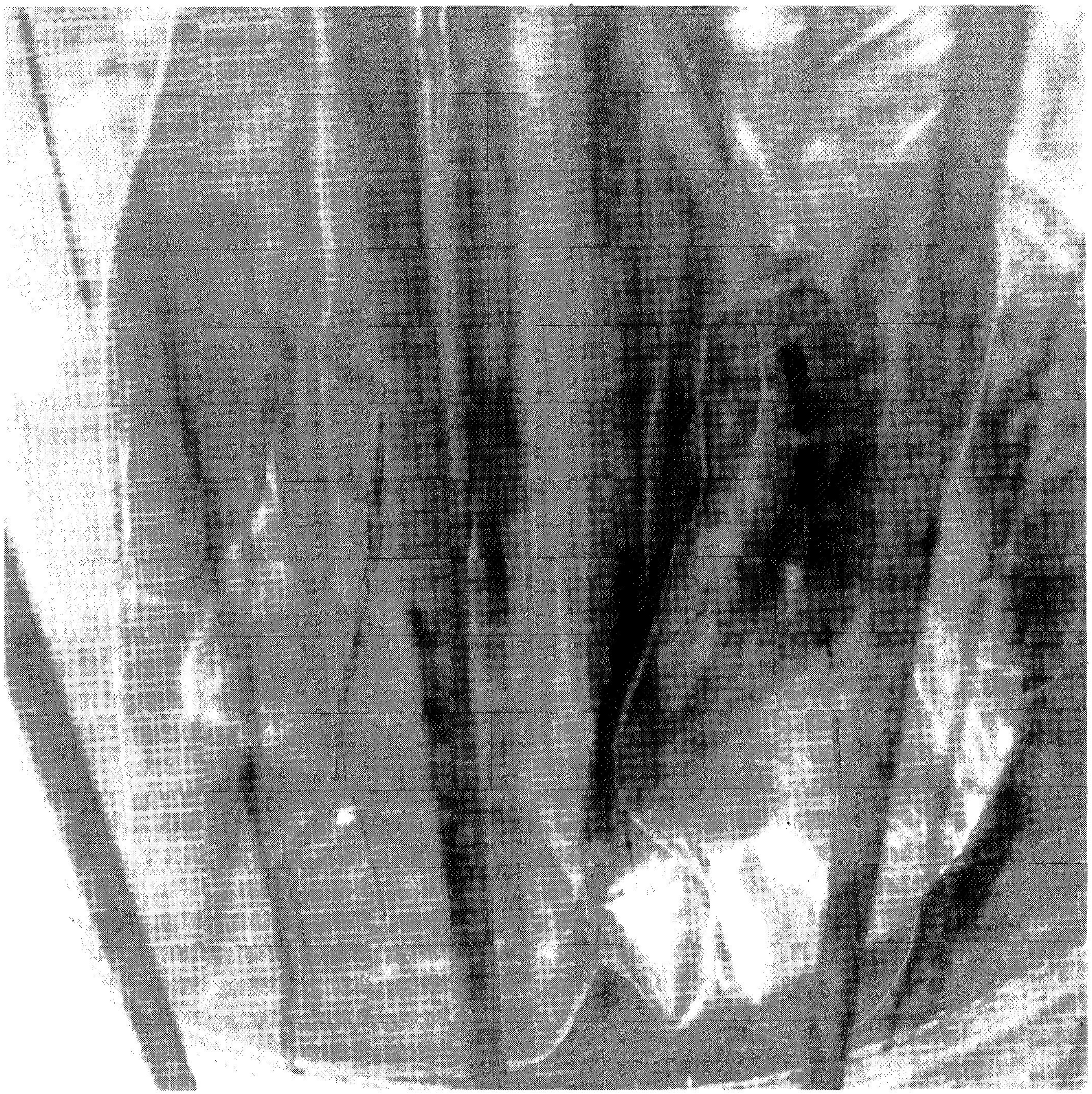

FIGURE 10. TEFLON/FOIL LAMINATE BLADDER - VERTICAL EXPULSION - 100% EXPELLED - BOTTOM VIEW

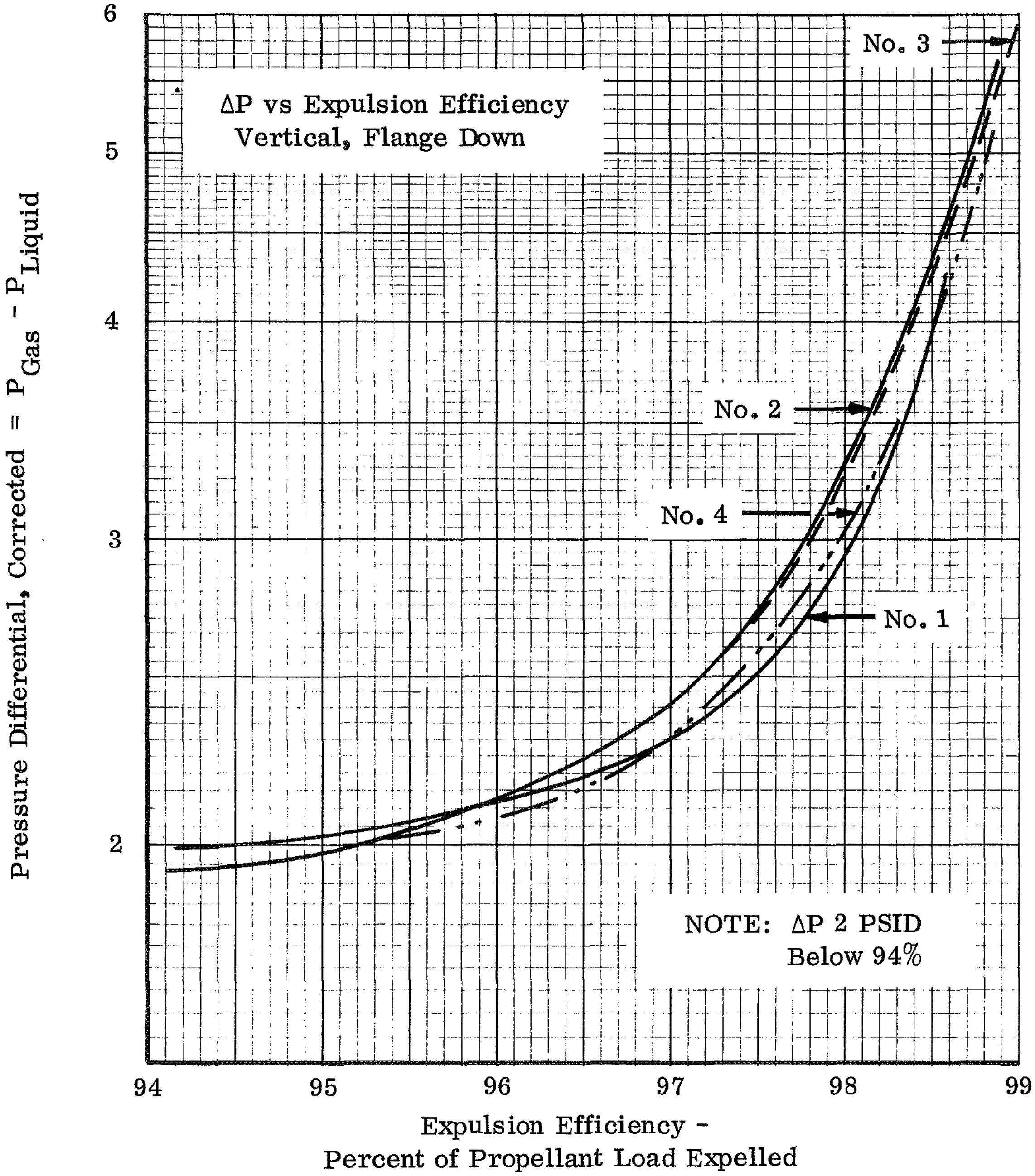

FIGURE 11. MODEL 8514 TEFLON/FOIL LAMINATE BLADDER PN 8514-471008-1 SN 70-1 EXPULSION TEST DATA

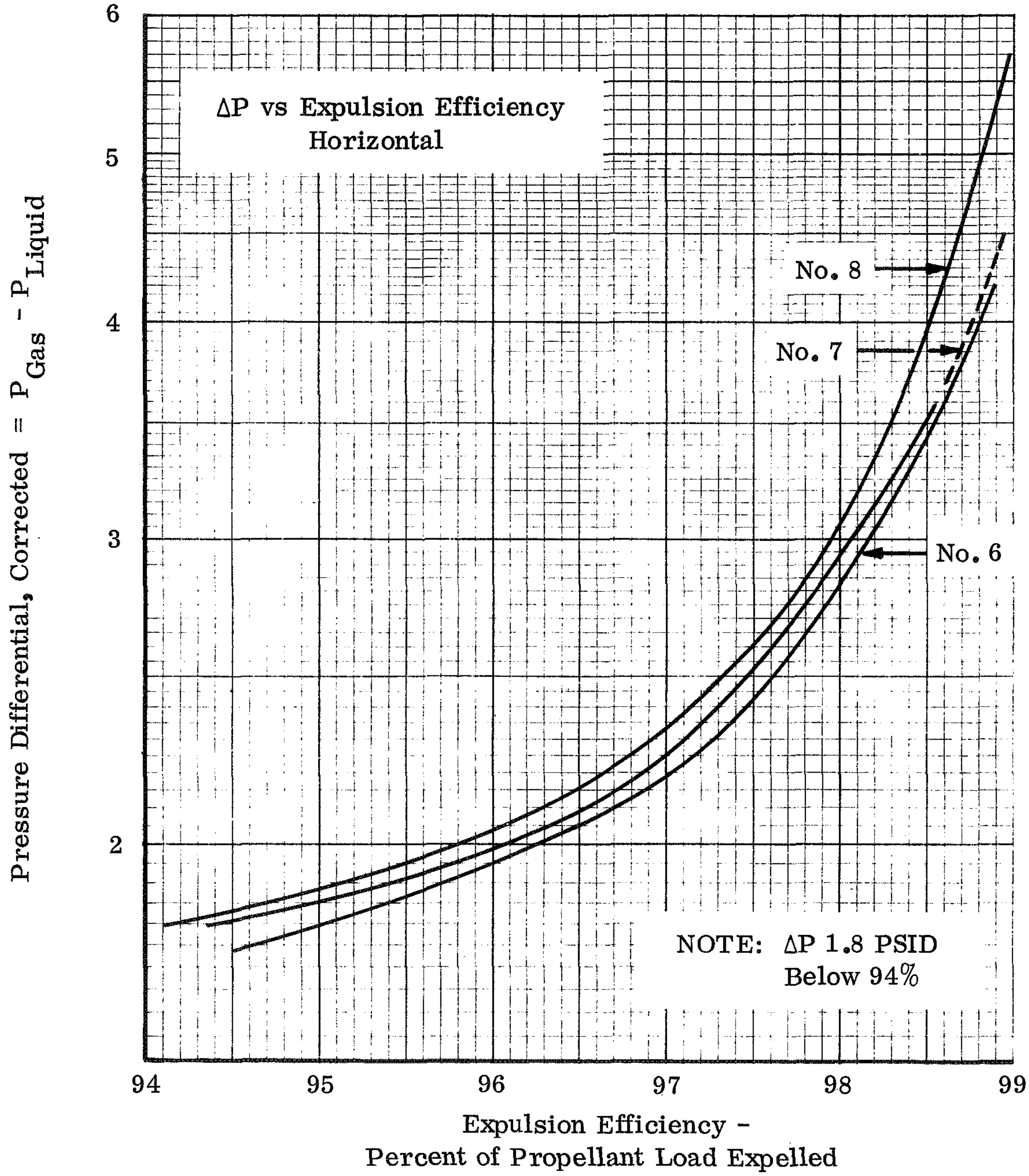

FIGURE 12. MODEL 8514 TEFLON/FOIL LAMINATE BLADDER PN 8514-471008-1 SN 70-1 EXPULSION TEST DATA

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FIGURE 13. TEFLON/FOIL LAMINATE BLADDER AFTER HORIZONTAL EXPULSION - TOP VIEW

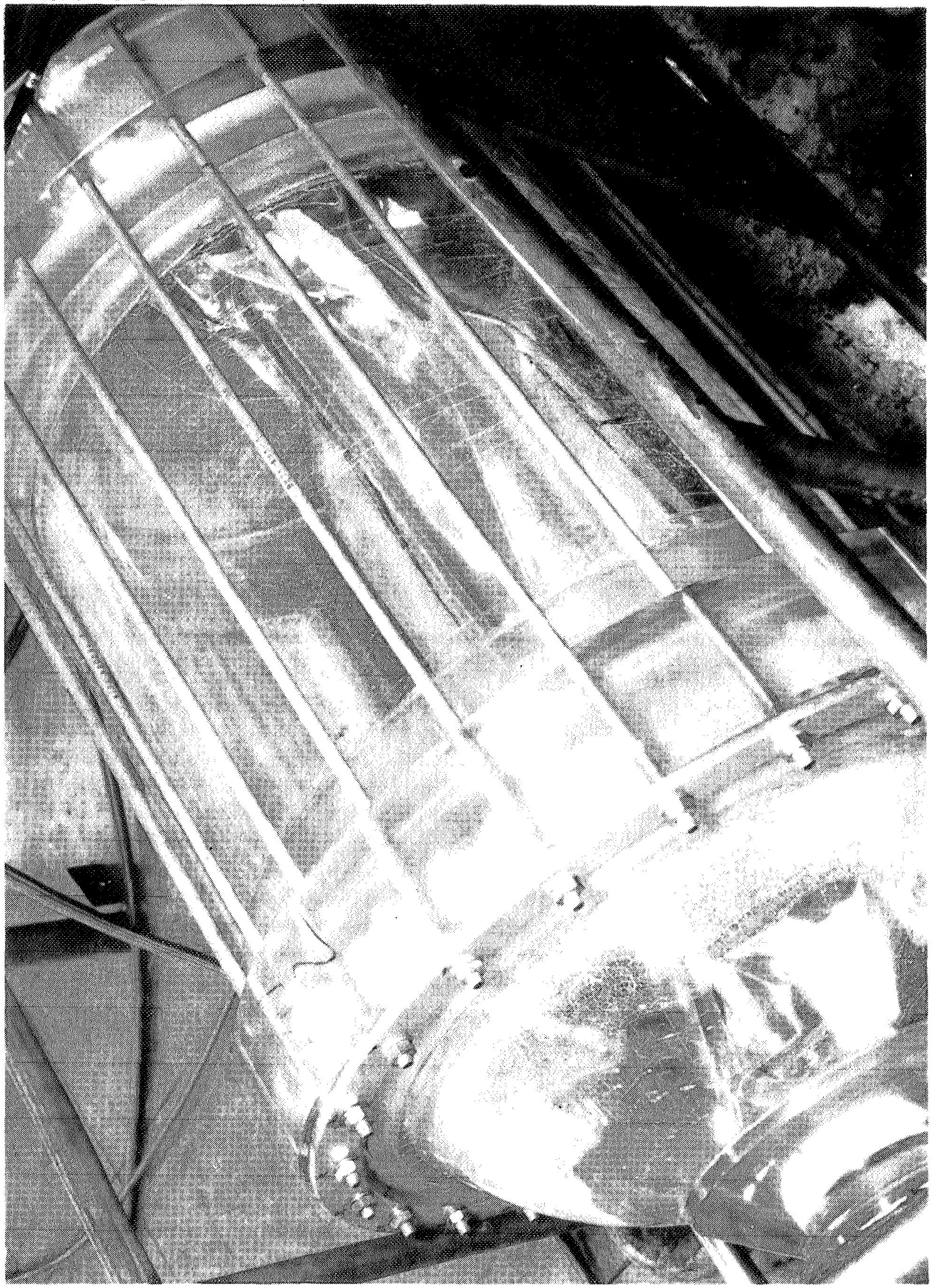


FIGURE 14. TEFLON/FOIL LAMINATE BLADDER AFTER HORIZONTAL EXPULSION - END VIEW

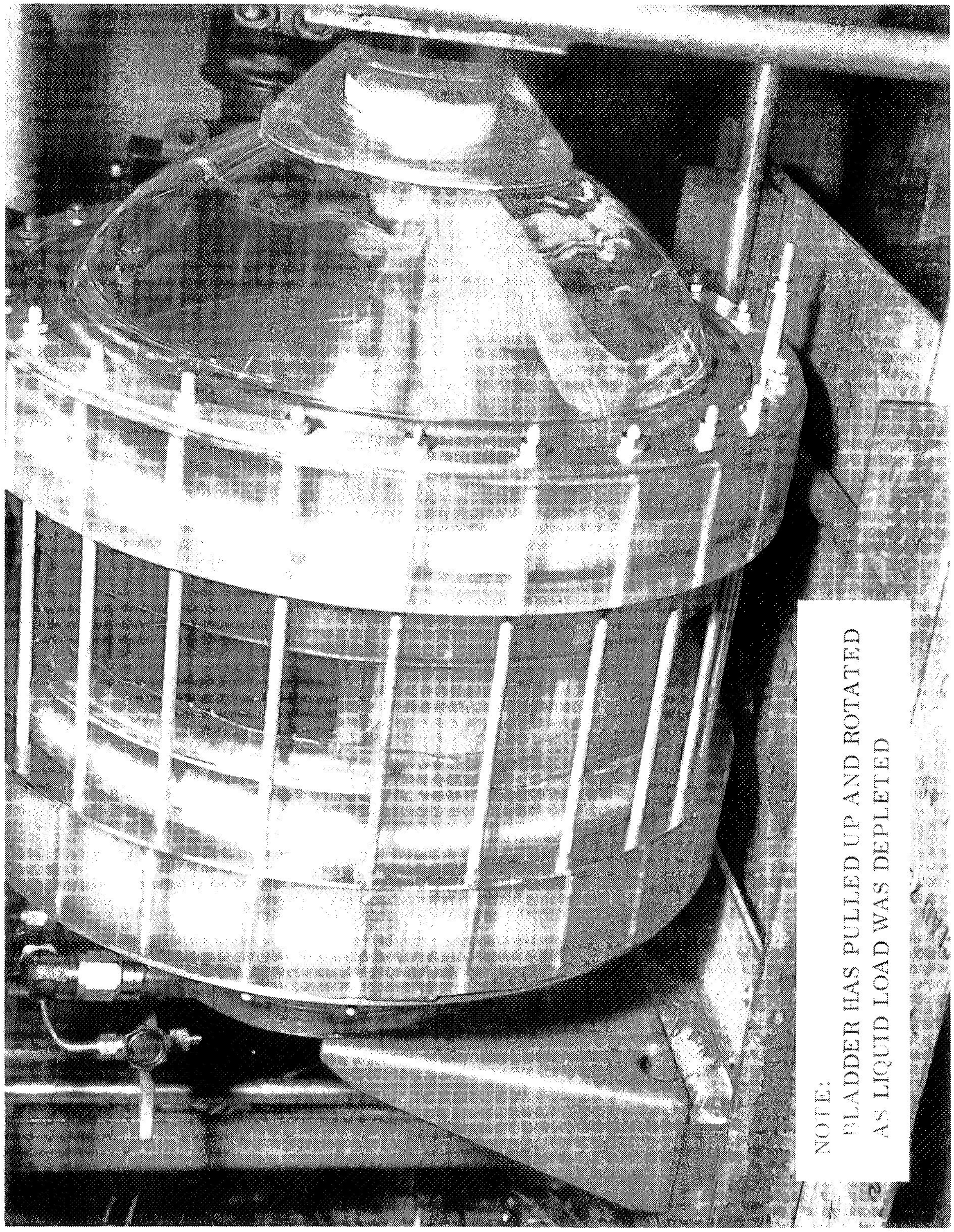
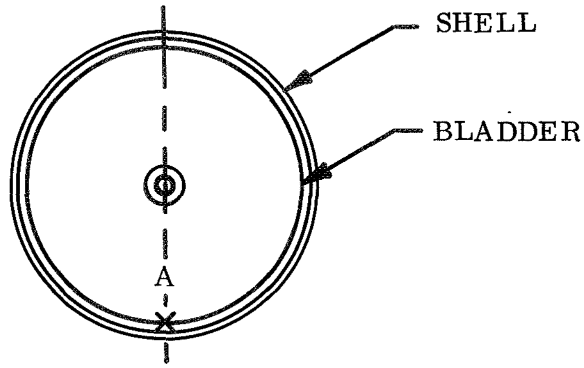
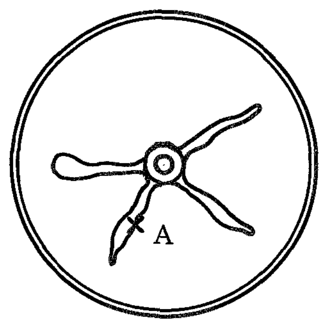


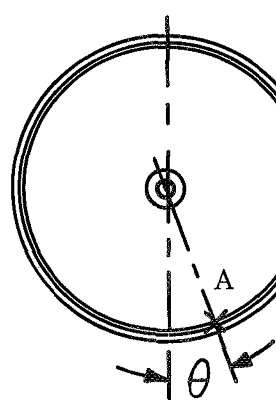
FIGURE 15. POST-EXPULSION BLADDER CONDITION IN HORIZONTAL CMO TANK



POSITION OF POINT A
PRIOR TO EXPULSION



POSITION OF POINT A
AFTER EXPULSION AND EVACUATION



POSITION OF POINT A
AFTER FILL

FIGURE 16. SKETCH SHOWING TYPICAL HORIZONTAL FOLDING PATTERN AND TWIST

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A. RETAINER END

B. FLANGE END

FIGURE 17. EXAMPLES OF TWIST DAMAGE ACCUMULATED DURING REPETITIVE EXPULSION CYCLING IN HORIZONTAL ATTITUDE

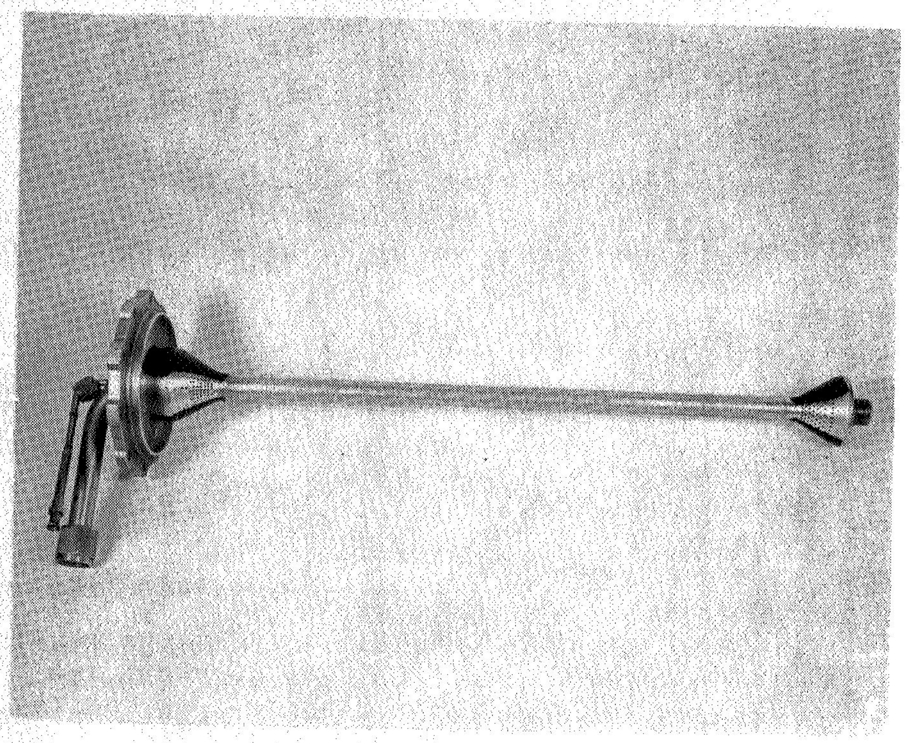

FIGURE 18. DIFFUSER TUBE ASSEMBLY - SHOWS MODIFIED CONES

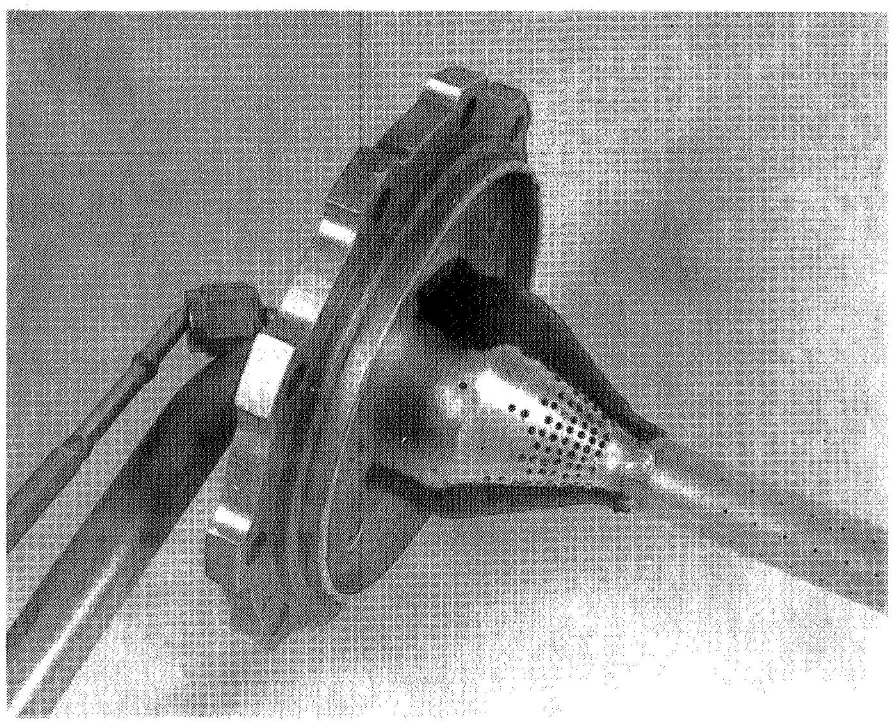

FIGURE 19. DIFFUSER ASSEMBLY: FLANGE END CONE - SHOWS TYPICAL SEALING OF HOLES TO CHANGE FLOW PATTERN

TABLE 1

EXPULSION DATA SUMMARY
PLEXIGLASS TANK TESTS
SMO UNDERSIZED BLADDER WITH ALUMINUM FOIL LAMINATE

EXPUL. NO.	W_{LOAD} LB	W_{EXPEL} LB	$W_{RESID.}$ INDIC.	FINAL η_e %	Δ P AT SHUTDOWN
1	159.1	157.7	1.4	99.12	7.10
2	159.5	157.7	1.8	98.87	5.66
3	159.5	157.9	1.6	99.00	5.94
4	159.45	157.9	1.55	99.03	5.88
5	159.6	157.95	1.65	98.97	6.06
6	159.35	157.45	1.9	98.81	4.16
7	159.75	156.85	2.9	98.18	3.08
8	159.45	157.75	1.7	98.93	5.54

NOTE:

EXPULSIONS NO. 1 THRU 4 - VERTICAL, FLANGE DOWN

EXPULSIONS NO. 5 THRU 8 - HORIZONTAL

TABLE 2

COMMAND MODULE OXIDIZER PLEXIGLASS TANK EXPULSIONS

Test Series	No. of Expulsions	Liq.	Tank Type	Bladder Config.	Pre-* Twist [Inches Clockwise]	Holes Std. No. & Size Except Where Otherwise Noted			Residual** Twist [Inches Clockwise]	Maximum Variation From Residual Twist (Inches)	Range of Twist [Inches From "0" Twist]	REMARKS
						Cone	Tube	Flange				
1	10	H_2O	C/MO	8271-471160 (9 mil ends)	4.5in.	Std.	Std.	Std.	3.0	3.0	3.0 to 6.0 CW	Baseline Test With Pre-Test Twist Held for 2 Hrs.
2	10	H_2O	C/MO		(1)	Std.	Taped	Std.	1.4	1.9	0.5 ccw to 1.5cw	No pretwist
3	8	H_2O	C/MO		(1)	Std.	Std.	Std.	1.0	1.8	0.8 ccw to 0.6cw	Re-run of Test Series #1 Without Pretwist, Results Similar to Test #2
4	8	H_2O	C/MO		4.5in.	Std.	Std.	Std.	4.0	7.5	1.5 ccw to 3.5ccw	Re-run of Test Series #1 With Pre-twist to Verify #1.
5	7	H_2O	C/MO		4.5in.	Std.	Taped	Std.	3.8	1.7	4.0 cw to 5.5cw	Re-run of Test #2 With Pre-twist
6	7	H_2O	C/MO		4.5in.	Std.	Std.	Std.	3.7	1.7	3.8 cw to 5.4cw	Baseline Test Repeated to Verify Twist Range
7	9	Freon T.F.	C/MO	8271-471148 (6 mil)	No	46 (.060) Dia.	Std.	60 (.060) Dia.	0	3.0	1.7 to 3.0ccw	Holes in End Cones in Bottom 90°, Quadrant Only, Drilled to 0.060 Dia.
8	8	Freon T.F.	C/MO		No	46 (.060) Dia.	Taped	60 (.060) Dia.	0	3.0	1.0 to 3.0ccw	Same as #7, Except Tube Taped
9	15	Freon T.F.	C/MO		No	92 (.060) Dia.	Taped	120 (.060) Dia.	0	+1.9 -2.8	1.9cw to 2.8ccw	Holes in End Cones in Top and Bottom 90° Quadrant.
10	8	Freon T.F.	C/MO		No	Std.	Std.	Std.	0	1.5	0.5 to 1.5 ccw	Baseline Test- Std. Diffuser.

* Twist: 4.5 in. = 36° Twist (or 8°/inch)

** Residual twist is measured twist in bladder when expanded with gas prior to first liquid load in each test series.

(1) Bladder was not pre-twisted but the residual twist used as pretest basepoint.

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APPENDIX A

ASSEMBLY AND LOAD PROCEDURE - CM PLEXIGLASS TANK

1.0 ASSEMBLY

(1) Assemble bladder assembly per standard acceptance test procedure.

(2) Mark bladder with longitudinal lines at 10 quadrants, using flange bolt location as reference.

(3) Install bladder assembly into plexiglass shell. Do not bolt, but align properly.

(4) Expand bladder with nitrogen gas to wall using 27 in. H_2O pressure.

(5) Complete tank assembly.

2.0 LOAD PROCEDURE

(1) Collapse bladder using 5 ± 1 psig nitrogen pressure. (Note collapse sequence.)

(2) Evacuate bladder to a minimum of 28 in. Hg vacuum.

(3) Using 20 psig nitrogen load pressure on source tank, open load valve and release vacuum, filling diffuser tube.

(4) Maintain 5 ± 1 psig back pressure and continue to load until the bladder assembly is 90% full, or 58 lb H_2O.

(5) Close fill valve. Note fill sequence bladder motion and record bladder twist in inches.

3.0 EXPULSION

(1) Increase gas side pressure to $15 \begin{smallmatrix}+0 \\ -5\end{smallmatrix}$ psig helium.

(2) Expel H_2O at a flowrate of 0.46 lb/sec. (Equivalent volume of 0.66 lb/sec N_2O_4.)

(3) Note bladder collapse during expulsion.

SIGNATURES

(Report Approval)

R. K. Anderson Date: 3/19/70

Program Manager - Model 8514
Bell Aerospace Company

R. M. Thompson Date: 3/19/70

Assistant Chief Engineer
Structural Systems Dept.
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R. V. From Date: 3/20/70

Defense Contracts
Administration Service
Coordination